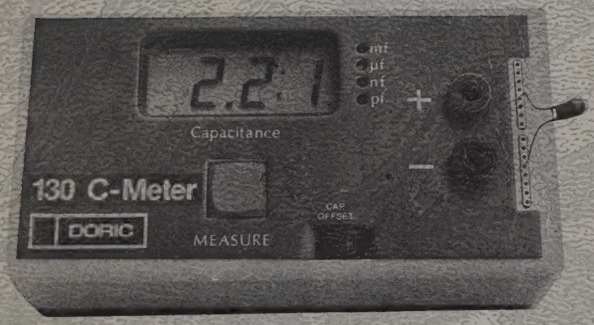
ME-7838

DORIC

OWNER'S MANUAL

C-METER

MODEL 130



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DORIC SCIENTIFIC DIVISION
EMERSON ELECTRIC CO.
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WARRANTY

Doric Scientific hereby warrants each instrument of its manufacture as follows:

1. At the time of delivery of each instrument to the original purchaser, Doric Scientific UNCONDITIONALLY WARRANTS that it shall be free from defects in parts, materials and workmanship; and

2. Commencing with the date of shipment of each instrument to the original purchaser, Doric Scientific UNCONDITIONALLY WARRANTS that each unit shall remain free from defect in parts, materials and workmanship for a period of 1 year.

In the event any instrument fails to meet the terms of this warranty, Doric Scientific agrees to provide corrective action. Contact Doric's Customer Service Department for handling instructions.

The warranties herein shall not obligate Doric Scientific in any manner whatsoever with respect to, and shall not be applicable to, any defects which after an inspection by Doric Scientific are not to Doric Scientific's reasonable satisfaction demonstrably the result of defective parts, materials or workmanship. We are not liable for consequential damages.

CERTIFICATION

Doric Scientific certifies that this instrument was thoroughly tested and inspected and found to meet its published specifications when shipped from the factory. Doric Scientific further certifies that its calibration measurements are traceable to NBS.

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SECTION 1

DESCRIPTION

1.1 GENERAL DESCRIPTION

The Doric Model 130 C-Meter is a precision digital autoranging capacitance meter that measures from 0.1 pF to 200,000 μF in 10 automatically selected ranges. Capacitance is indicated on a liquid crystal display with 0.6 inch high numerals. Four light-emitting diodes indicate whether the displayed readout is in pF, nF, μF or mF units. After the capacitor is attached, a push-to-measure button on the front panel activates the measurements. An offset potentiometer is also located on the front panel for nulling out stray capacitance from test clips, leads, etc.

You will find the Doric C-Meter extremely versatile and easy to use. Its compact size and portability offer time-saving convenience and its accurate, rapid readings provide numerous applications (see Section 6). The complementary metal-oxide-semiconductor (CMOS) integrated circuitry and liquid crystal display require very little current. In fact, the batteries should last at least a year with normal use.

In addition to the built-in connector strips, the C-Meter includes a variety of test clips to accomodate all types of capacitors. To test a capacitor, just discharge it, connect it to the C-Meter and press the button.

1.2 PHYSICAL DESCRIPTION

The C-Meter measures 2.25 inches (5.72 cm) in height, 3.15 inches (8.00 cm) in width, and 5.90 inches (15.0 cm) in length. Weight is 15.0 ounces (425 gm).

1.3 UNPACKING

The C-Meter is shipped with a nylon packing screw in the external power jack, on the left side panel. This disables the push-to-measure switch and avoids inadvertent battery drain during shipment. Remove this screw before operation.

1.4 SPECIFICATIONS

Range:	10 automatically selected ranges from 199.9 pF to 199.9 mF (199,900 μF) full scale.
Accuracy:	0.1% of reading $\pm$ 1 count from 0.1 pF to 200 μF. 1% of reading from 200 μF to 199.9 mF. Accuracy is maintained over temperature range of 15 to 35°C (59 to 95°F). Capacitor leakage tolerance for rated accuracy is 40k Ohm equivalent parallel resistance in 200 μF and higher ranges, 2 megohms in 200 nF to 199.9 μF range, 2000 megohms with smaller capacitors.
Display:	3½ digit liquid crystal display with 0.6 inch numerals. 4 light-emitting diodes indicate pF, nF, μF and mF. Readout is always between 200 and 1999, except on lowest range, regardless of decimal point.
Controls:	Front panel has push-to-measure button, and an adjustment for nulling up to 15 pF of stray capacitance from test leads and clips.
Test Parameters:	RC time constant of the unknown capacitor and standard resistance is measured. Maximum voltage applied is less than 4 volts dc and maximum current is less than 20 mA.
Display Rate:	Less than 600 ms between readings, except that the rate decreases to one new reading every 5 seconds at 199.9 mF. Readout shows 00.0 mF until valid reading is obtained.
Operating Temperature Range:	Although the C-Meter functions properly from 40 to 122°F (5 to 50°C), calibration accuracy is slightly degraded at extreme temperatures.
Power:	Four internal penlite batteries (1.5 volt dc, size AA) supply power. An external power supply can be used, although batteries always supply input biasing with negligible current drain and must remain connected. Internal regulations permit use of unregulated power supplies of 5 to 10 volts dc, with a 200 mA peak surge current drain at startup.

SECTION 2

OPERATION

2.0 OPERATION

2.1 CONNECTING THE CAPACITOR

A variety of methods are provided for connecting a capacitor to be tested to the C-Meter.

a. The built-in connector strips on the right hand edge of the front panel accept capacitor leads up to #20 gage. Leads are inserted as shown in Figure 2-1; one lead in the upper strip and one lead in the lower strip. Components with leads as short as 0.1 inch may be used on these connector strips.

b. The banana jacks (marked "+" and "−") to the left of the connector strips measure larger axial lead capacitors through the use of component clips which plug into the banana jacks as shown in Figure 2-2. Capacitors on rolls may also be tested without removing them. Care should be exercised to align the polarity poles (+ to +, − to −) where applicable.

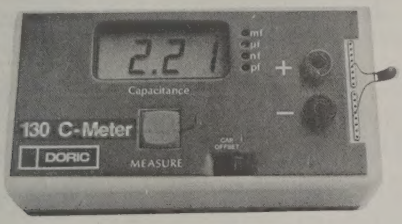


FIGURE 2-1. INSERTING CAPACITOR LEADS INTO CONNECTOR STRIPS

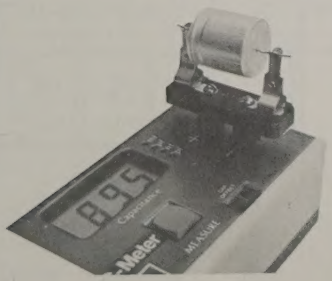


FIGURE 2-2. MEASURING CAPACITOR WITH COMPONENT CLIP IN BANANA JACKS

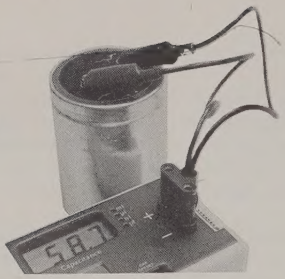


FIGURE 2-3. USING CLIP LEADS TO CONNECT SCREW TERMINALS CAPACITORS

c. Alligator clips may be connected to power line phase-compensation capacitors enabling linemen to check capacitors before resetting a blown power line circuit breaker. The banana jacks provide the interface with the C-Meter for this type of operation. Care should be exercised to align the polarity of the terminals with the leads as applicable.

WARNING: All capacitors must be discharged before connection to the C-Meter. Extreme care should be exercised when making measurements near circuits carrying lethal voltages.

2.2 ADJUSTING THE OFFSET CONTROL

The "Capacitance Offset" potentiometer, location on the front panel, is used for nulling out stray capacitance from test clips, leads, etc. With the test leads in place, adjust pot until display reads all zeros when measurement button is depressed. The leftmost decimal point turns on if adjusted too far, indicating a negative reading.

2.2.1 Additional Offset

If the capacitance of the test jig exceeds 15pF, the offset cannot be nulled by the "Capacitance Offset" control. In such cases, there are two adjustments inside the C-Meter that can extend the offset range (refer to Figure 2-4).

a. Adjust trimmer C26 to remove up to 20 pF from the minimum reading. This permits 35 pF to be offset instead of 15 pF.

b. Cut the wire loop in front of R1 to remove an additional 68 pF from the minimum reading. This permits a total of 103 pF to be offset.

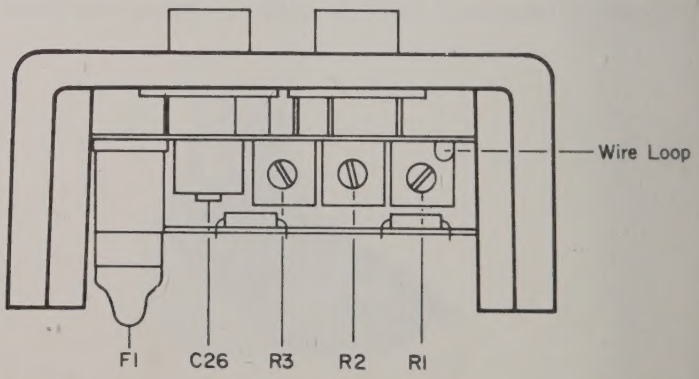


FIGURE 2-4. FUSE, OFFSET ADJUSTMENTS, AND CALIBRATION POTENTIOMETERS

2.3 TESTING THE CAPACITOR

With the offset nulled, discharge and attach the capacitor to be tested, then depress the "Measure" button. Capacitance value reads out directly.

NOTE: Although the input to the C-Meter is protected, large value or high voltage capacitors can blow the input fuse if not discharged before being connected.

2.3.1 Large Capacitors

Physically large capacitors of smaller value may pick up 60 Hz hum from the environment. This hum can be minimized by connecting the minus terminal of the meter to the capacitor electrode with the most shielding value, such as the stator of an air variable capacitor or the shield of a coaxial cable.

2.3.2 Lossy Capacitors

Lossy capacitors indicate different values when measured by different techniques. The measurement technique used by the C-Meter does not need to cancel out dissipation factor effects in order to obtain an accurate reading, as does a bridge. However, with very lossy capacitors, the two techniques give different results. In addition, dielectric absorption causes the apparent value of large capacitors to decrease somewhat during measurement. This is explained in Section 7 and should be read before making precise measurements of capacitors whose measured values are a function of test parameters, and therefore do not maintain precision under differing operating conditions.

2.4 POWER

In most lab use, four standard "AA" penlite alkaline cells should last about one year. Low batteries are indicated by flashing of the liquid crystal display and the LED range indicators. Battery condition does not affect meter accuracy until this occurs.

NOTE: Do not mistake weak batteries for a failure of the meter. Replace the batteries before returning the meter for service.

To change batteries, remove the four corner screws on the bottom of the meter, and gently pull the two halves of the box apart. The battery holder is located on the inside bottom of the box, and the batteries snap in and out.

External power can be applied via the miniature phone jack on the left side panel, with the plug tip connected to the positive (+) side of the supply. This need not be regulated or well filtered, but must be between 5 and 10 volts dc, capable of up to 200 mA surge and 80 mA sustained current. Actual drain is usually far lower. External power bypasses the push-to-measure switch, permitting continuous measurement. The batteries must, however, remain installed at all times when the meter is being used.

To prevent the possibility of damage due to leaking batteries, alkaline cells are recommended. These will also provide somewhat longer life than carbon-zinc cells.

SECTION 3

THEORY OF OPERATION

3.0 THEORY OF OPERATION

The C-Meter measures capacitance by determining the RC time constant of the capacitor under test and a standard resistor. This is done by precisely measuring the time that the capacitor takes to pass through two reference levels of voltage as it is being charged. Autoranging is accomplished by taking all initial measurements in the highest range (199.9 millifarads full scale) and rapidly progressing down through the ten ranges until a count is reached between 200 and 1999, independent of decimal point. At this point, or on the lowest range if it is reached first, the time value as counted is displayed, along with the proper decimal point and scale LED. After a pause, another measurement sequence begins.

3.1 MEASUREMENT SEQUENCE

Every measurement cycle begins with the range counter IC13 at "A". Each capacitance trial, starting at "A," is sequenced by timing capacitor C22 charged through R50 and measured by Schmitt trigger IC1. When the voltage on C22 reaches the upper threshold of IC1, a trial begins. This is time T1 (see timing diagram, Figure 3-1) and IC4 pin 15* goes high, which starts the capacitor under test charging.

*__NOTE:__ This is referred to as 4/15, with the IC number followed by the pin number.

The capacitor being tested is placed across C26 and C35; diodes D1 and D2 and fuse F1 protect the analog input circuitry against damage from charged capacitors. Q1 discharges the capacitor between trials; it is turned off at T1. Voltage follower Q7 (A and B of a matched dual FET) samples the voltage on the capacitor and in turn feeds the 311 comparator, IC27, which compares the capacitor with a reference voltage determined by R13, R14, R15, Q5, and, in the highest range ("A"), R16 and Q6. When the capacitor reaches the first reference voltage, Q5 turns on; this is T2.

At this time, the comparator sets latch 8/10; Q5 sets the input comparator IC27 to await a second threshold. 8/10 feeds delay circuit IC2, which introduces the capacitance offset on the lower ranges. The output of this circuit, 3/3, goes low at T2'. Should this occur after the capacitor under test reaches the second threshold, T3, the negative capacitance latch 8/1 turns on, providing the extra decimal point that indicates excessive compensation.

The comparator IC27 goes low when the second threshold is reached (T3). This sets 6/3, and C22 begins discharging through R62 and Q12. 6/11 turns off counter gate 11/3, which is between the crystal oscillator IC11 and the divider chain. 11/3 is counting from T2' to T3, or from T3 to T2' if the count is "negative." When C22 falls to the lower threshold of IC1, which then changes state, the unknown capacitor begins to discharge through Q1; this is T4.

Front-end comparator IC27 goes high again when the tested capacitor falls to the lower threshold. Shortly thereafter, the counters are cleared. If the count reaches 200 with the range being tested, the counter latches are strobed to display the value. If the trial is unsuccesful, C22 is only allowed to discharge to the lower threshold of IC1, and IC13 is advanced one range. The lower threshold of IC1 is not much different from the upper, so there is only a very short delay between the end of one trial, T5, and the start of the next (T1). Nine unsuccessful trials can take place within 100 milliseconds. The tenth trial ("J," 199.9 pF full scale) is always displayed if reached.

If the trial is considered successful, C22 is discharged to approximately one volt. C22 takes about half a second to recharge to its upper threshold; during this time, the count is displayed on the liquid crystal display. IC13 has ten output lines, which are gated to produce the proper combination of scale LED, decimal point, and counter frequency for the range being tested (See Figure 3-2). After the final trial of a cycle, IC13 is cleared and the procedure repeats.

The actual voltages used by comparator IC1 are approximately 4.05 and 4.15 V dc, while IC27, the front end comparator, has its lower threshold around 0.71V and its upper threshold at 2.77 V. This ratio results in an interval between thresholds of approximately .988 RC. On range "A," Q6 changes the two thresholds to approximately .044 V and .417 V; the time interval is then 0.0988 RC.

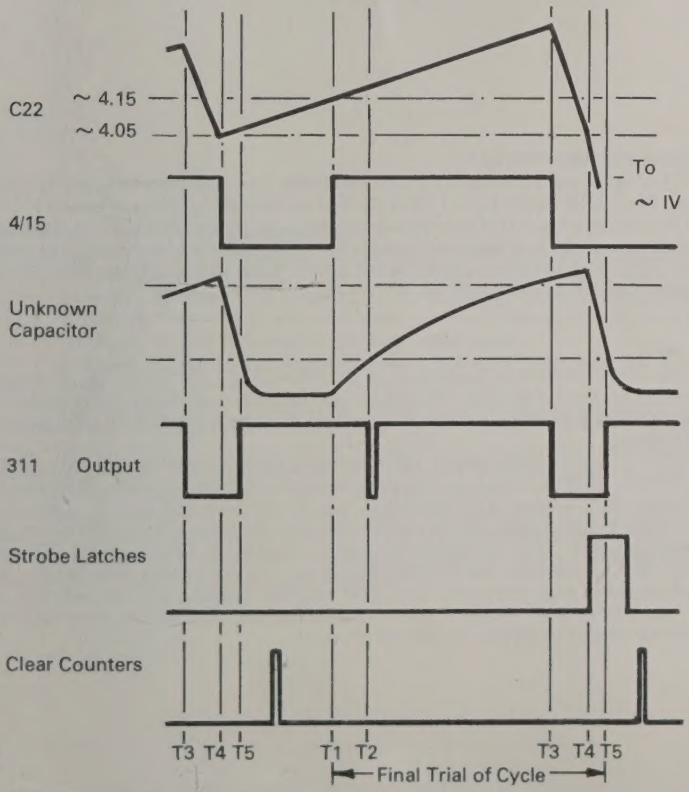


FIGURE 3-1. TIMING DIAGRAM

STATE	RANGE	CHARGING RESISTOR	COUNTING FREQUENCY	VOLTAGE V2
A	20-200mF	200Ω	500Hz	0.42
B	2-20mF	200Ω	500Hz	2.7
C	200-2000μF	200Ω	5kHz	2.7
D	20-200μF	2k	5kHz	2.7
E	2-20μF	2k	50kHz	2.7
F	200-2000μF	2k	500kHz	2.7
G	20-200nF	2k	5MHz	2.7
H	2-20nF	2M	50kHz	2.7
I	200-2000pF	2M	500kHz	2.7
J	0-0200pF	2M	5MHz	2.7

FIGURE 3-2. RANGE TEST PARAMETERS

3.2 COUNTING AND DISPLAY

The 5.0 MHz crystal oscillator (IC11) provides the precision time base for the counter circuitry. The 5 MHz signal from 11/3 is divided by decade counters IC16 and IC17. The proper amount of division for the range being tried is selected by multiplexers IC14 and IC15, which are controlled by range counter IC13. The selected frequency is counted by IC20 and IC22, which feed the latch/display drivers IC19, IC23, IC24 and IC25. Oscillator IC18 generates the ac drive voltage for the liquid crystal display.

3.3 POWER

The meter is powered by 4.3 to 6 volts, provided by 4 "AA" cells. This is internally regulated to produce the +4 volts used to run the analog portions of the C-Meter; an inverter-regulator system produces +13 volts that powers the CMOS logic and liquid crystal display.

Q10 and Q11 form a self-starting, self-oscillating flyback inverter, with a frequency of approximately 150 kHz. Its output is feedback regulated by zener diode D4 to a nominal 13 ±1 volts. IC26, a type 723 regulator IC, regulates the 4 volt supply. If the battery voltage drops below 4 volts, excess current is drawn through R28 into the V + terminal of the 723 regulator. This voltage drop triggers monostable Q8-Q9, which temporarily removes the 13 volts from the display drivers. As the drop across R28 is reduced by this, the power is then restored. This cycle repeats, flashing the display. The liquid crystal has a long time constant when viewed straight on, but the blinking is more pronounced when the display is viewed off axis.

SECTION 4

MAINTENANCE/ TROUBLE SHOOTING

4.0 MAINTENANCE/TROUBLESHOOTING

Routine maintenance of the C-Meter consists essentially of changing batteries when necessary. In the event that the C-Meter is connected across a large value charged capacitor, fuse F1 will blow. This is indicated by a display value independent of the capacitor under test; it usually appears to be about −75 pF (the leading decimal point is on), and is affected by the "Capacitance Offset" adjustment.

Fuse F1 is a type 112 light bulb. Do not replace it with any other type. It is in a socket accessed by removing the back of the box. See Figure 2-4.

If the meter displays flash, the batteries are low and should be replaced. If pressing the button gives no effect at all, it is likely that a power connection within the meter is broken. This may be to the battery holder, the switch, or the external power jack. Check these connections before returning the meter for service. Do not operate the meter on external power without a working set of batteries installed.

Other repairs should not be attempted unless the repairman is accustomed to the precautions necessary for working with CMOS IC's. The two printed circuit boards should not be separated unless both the boards and workman are grounded. Use only a grounded soldering iron when making repairs.

SECTION 5

CALIBRATION

5.0 CALIBRATION

The C-Meter is shipped fully calibrated. Recalibration should be done semi-annually if maximum accuracy is necessary for the intended application.

Calibration is simple, requiring only a screwdriver and three precision capacitors. The first capacitor should be somewhere between 100 pF and 19.99 nF; the second should be between 100nF and 199.9 μF; the third should be greater than 200 μF. The values of the first two capacitors should be known to at least 0.1%, and preferably 0.01%. The highest value need only be accurate to better than 1%, although 0.1% is recommended. Values just *under* 2 times a power of 10 gives the best resolution, as the meter reads from 200 to 1999 on each range.

Calibration can be done with commercial standard value capacitors, or with good quality film capacitors measured on a precision bridge. Many types of capacitors are incapable of precision measurement, as their indicated capacitance is very much a function of the test parameters. For this reason, lossy or drift-prone capacitors should be avoided, along with ceramics and aluminum electrolytics. Good quality film capacitors should be used for the lower ranges, and a low-loss tantalum capacitor should be used for the top range. Since all electrolytic capacitors are to some extent affected by frequency, the standard tantalum should be measured with a bridge at as low a frequency as possible.

The first step in calibration is to zero the capacitance offset via the front panel control, as outlined in the previous section. The three range adjustments are non-interactive, so they can be made in any order. With the lowest of the three standard capacitors inserted, adjust R1 (see Figure 2-4) for the correct value on the display. Repeat with the midrange capacitor and R2; R3 adjusts the ranges above 200 μF. This completes the calibration. Lift the edge of the shield to access R1, R2, R3 and the wire loop.

SECTION 6

APPLICATIONS

6.0 APPLICATIONS

The versatility of the C-Meter lends it to many applications for which capacitance measurement has not traditionally been used. It is so much easier to use than a bridge that many users now measure capacitance more readily than resistance. Not only is the C-Meter useful for testing capacitors, it permits incidental capacitance of conductive circuits to be used as a tool for troubleshooting and length measurement.

6-1 ENGINEERING LAB APPLICATIONS

While most electronic laboratories have access to an impedance bridge, it is little used. The small size and convenience of the C-Meter provides for many applications:

- Measuring the value of capacitors for timing circuits
- Selecting and matching capacitors for filters of any type
- Measuring temperature and voltage coefficients of capacitors
- Measuring or confirming the value of obscurely marked or coded capacitors
- Analyzing failed circuits
- Measuring the value of a variable capacitor that is to be replaced by a fixed capacitor
- Finding capacitors at specified tolerance limits, to verify circuit operation at extremes
- Measuring interelectrode capacitance in tubes and junction capacitance in semiconductors
- Measuring stray capacitance and gimmicks
- Adjusting linearity of large variable capacitors

The C-Meter readily lends itself to new applications. The addition of the C-Meter to a lab's instrument supply decreases design time and the uncertainties encountered in circuit development.

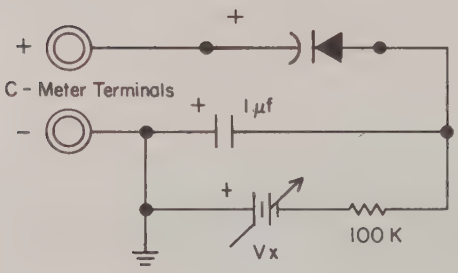
6.2 MEASURING VOLTAGE VARIABLE CAPACITORS

Reverse biased semiconductor junctions have a capacitance value that varies with applied voltage. This principle is the basis for the varactor diode, but makes measurement of diode or transistor capacitance difficult.

The C-Meter can be used to make these measurements. It measures the charge storage ability of the capacitor under test as the applied voltage swings over a range of 0.71 to 2.77 V. The applied voltage range causes the capacitance indicated to correspond to the value for a bias of about −1.5 V. This figure varies slightly between different types of junctions, which may have different voltage vs. capacitance curves.

Diodes of a similar nature can be compared and matched directly using the C-Meter. Precise measurement of capacitance, however, requires that the effective bias value be known. This is best determined by making measurements on a bridge whose ac component is 50 mV or less, with a known external bias. Adjusting this bias to give the same reading as the C-Meter's allows direct measurement of equivalent bias.

Higher bias readings may be obtained by using the test setup shown in Figure 6-1. The average bias across the diode will be about 1.7 volts higher than the battery voltage. If this circuit is used, the C-Meter is not damaged if the diode breaks down.



The formula to convert from kVAR to μF is:

$$C = 2.65 \times \frac{kVAR}{kV^2}$$

FIGURE 6-1. TESTING CAPACITANCE VS. VOLTAGE WITH C-METER

6.3 DETECTING FAULTY POWER LINE PHASE-COMPENSATION CAPACITORS

A blown power line circuit breaker can pose a difficult repair problem. If the cause was simply a line transient, resetting the breaker is adequate. But if a phase-compensation capacitor is defective, it may explode. To be safe, the capacitors should be checked before resetting the breaker.

Checking the capacitors with a bridge is expensive, slow and clumsy, normally requiring that the capacitors be lowered from the pole. It's far better to measure the capacitance across each phase separately, using a hand-held digital capacitance meter. The capacitors need not be disconnected, other than by opening the breaker. The capacitor to be measured must be de-energized with a shorting bar. If capacitors are in parallel, it is also necessary to remove one of the bussing wires, so that each can be measured separately.

A capacitor can be assumed faulty if it differs from the others by more than 15% of indicated capacitance. Utilizing the C-Meter, faulty capacitors may read higher or lower in value; shorted units read zero. If no problem is found, or once the faulty capacitor is replaced, the circuit can then be safely re-energized.

6.4 LOCATING BREAKS IN BURIED CABLES

A hand-held digital capacitance meter provides a simple, accurate method for locating breaks in buried cables. Capacitance in a given buried cable is directly proportional to length. It is thus simple to locate a cable fault by measuring the capacitance from both ends. The percentage of the total capacitance measured from one end is the same as the percentage of cable from that end to the break. See Figure 6-2.

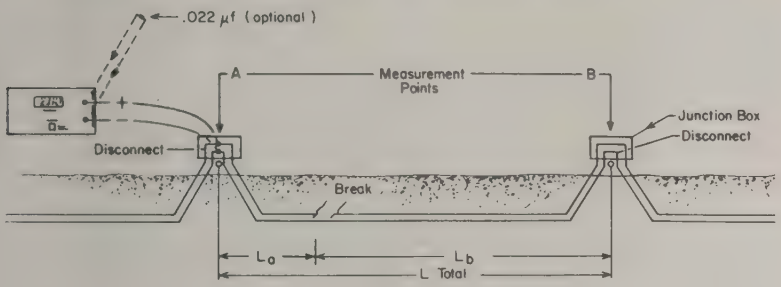


FIGURE 6-2. TEST SET UP FOR LOCATING BREAKS IN BURIED CABLES.

Buried cables frequently have more capacitance to ground than to themselves. In such cases, the unbroken conductor should be attached to the earth ground, along with the negative terminal of the C-Meter. The broken conductor is then attached to the positive terminal, and readings are taken.

The number of picofarads per foot of a given type of cable is relatively constant. This characteristic capacitance permits a cable to be measured from only one end. This is necessary if the leakage is too much to get an accurate C-Meter reading.

Sensitivity to both leakage and electromagnetic interference can be reduced by using a fixed offset capacitor of 0.022 uF. This forces the C-Meter to read in a range that has less susceptibility to such inaccuracies.

6.5 MEASURING COAXIAL CABLE LENGTH

Manufacturers of coaxial cables specify the characteristic capacitance of each type of cable. Coax rolls and installations of unknown electrical length (such as broken cables) can be measured accurately with a single C-Meter reading. Simply divide the C-Meter reading by the characteristic capacitance, in pF/ft., for an indication of length.

The shield of the cable (braid or outer conductor) should be connected to the "—" terminal of the C-Meter. This terminal is grounded to the front panel of the meter, and prevents extraneous noise pickup from causing the C-Meter to read erratically.

If the characteristic capacitance of a cable is not known, it can be easily determined by measuring the capacitance of a known section and dividing by the length. This also works with many non-coaxial cables although they may not show the same degree of consistency.

WARNING: All capacitors must be discharged before connection to the C-Meter. Extreme care should be exercised when making measurements near circuits carrying lethal voltages.

SECTION 7

ABOUT CAPACITORS

7.0 ABOUT CAPACITORS

There's more to a capacitor than meets the eye. We often find this out in unexpected ways. Capacitors have numerous imperfections that affect their measured values, and these can cause the same capacitor to behave differently in dissimilar circuits.

The effects of these imperfections can reduce the precision with which a capacitor can be measured. If the resulting inaccuracy exceeds one part per thousand, it is meaningless to specify the value of the capacitor to three places of accuracy, unless the specific test conditions are also described. Two capacitors with the same measured value may behave differently under circumstances other than those used in making the measurements. While some capacitors are more consistent than others, none are truly perfect.

These imperfections reveal themselves when trying to measure the value of a capacitor with two different pieces of test equipment. The readings may disagree, even though neither is actually erroneous. This is because different testing methods respond differently to the various imperfections.

Most capacitance measurements have been performed using a bridge. This method involves measuring a capacitor's impedance at a specific frequency, nulling out the resistive component, and calculating the capacitance from the formula for reactance.[1]

A different technique is to measure the capacitor's charge storage capabilities via the RC time constant at a particular voltage. This is based upon the fact that capacitance is the ratio of charge to voltage,[2] and capacitance, measured in Farads, is equal to the time constant in seconds divided by the resistance in Ohms.[3]

Theoretically, the two measurement techniques show identical values of capacitance. However, these readings are affected differently by the inherent imperfections of real-life capacitors, each of which can be important at various times. They include:

voltage coefficient,
temperature coefficient (tempco),
leakage,
effective series resistance (ESR),
effective series inductance (ESL),
dielectric loss,
and dielectric absorption (DA)

as well as the more complex dissipation factor (D), which is familiar to all bridge users. All merit further examination.

1. Capacitance is derived from reactance by the formula:

$$C = \frac{1}{2\pi XF}$$

in which X, capacitive reactance, is the imaginary part of the complex impedance (Z).

2. The formula $C = Q/V$, the formal definition of capacitance, can be integrated to $E = e^{RC/t}$ ($e = 2.71828$), which relates stored charge to capacitance.

3. $C = t/R$ is usually computed with seconds, microfarads and megohms as $t = RC$, the formula for time constant.

7.1 THE CAPACITOR'S HIDDEN FLAWS

The voltage coefficient of a capacitor refers to the change in capacitance with respect to a change in applied voltage. It is frequently expressed as that percentage of zero-bias capacitance that is found when the capacitor is used at its rated working voltage. In some high density ceramics, the capacitance falls by as much as 60%. Some electrolytics show higher capacitance at full voltage, while some show lower. Thus, with some capacitors, a measured calue only applies at a specific voltage.

The temperature coefficient is the rate at which capacitance changes with respect to temperature. It is generally measured in parts per million per degree Celsius. This value varies widely among the different types of capacitors, and is most pronounced with electrolytics. Capacitors of known tempco are used to counter the effects of heat in critical applications. While capacitors generate little heat on their own, they are often in locations where the temperature varies widely. Readings made at room temperature may therefore differ from in-circuit values.

An ideal capacitor is a perfect insulator to dc, but many dielectrics have measurable conductivity. This leakage contributes to losses in the circuit, although proper choice of dielectric can minimize the problem. In some instances, the case of the capacitor has a small but measurable leakage between the leads.

Leakage is usually specified as the product of the leakage resistance and the capacitance; this is the self-discharge time constant of the capacitor. It is usually most important at very low frequencies, when the leakage time is a noticeable percentage of the cycle time. At other times, it is one of the least significant imperfections. Figure 7-1 lists typical leakage values for different dielectrics.

While leakage manifests itself most strongly at dc, the dielectric loss of a capacitor is a hysteresis effect that causes most of the loss within capacitors. It rises with frequency, as dielectric materials do not change polarity without loss.

The leads and plates of a capacitor are not perfectly conductive. They have an effective series resistance (ESR) that also consumes some power. The electrolyte in electrolytic capacitors also contributes to the ESR.

Dissipation factor is defined as the ratio of energy lost to energy stored per cycle,[4] and it is the result of dielectric loss, leakage, and ESR. Bridges measure D because they need to compensate for it in order to get an accurate capacitance reading. Charge storage measuring techniques neither need nor measure D; knowledge of D is useful in very few circuits.

Bridges use either series or parallel resistance to compensate for D. The models that they use are shown in Figure 7-2. With many types of capacitors, D is usually low enough to have no effect on the measured capacitance, except at extreme frequencies. D is usually a nonlinear function of frequency, temperature and voltage, so each must be specified along with the value of D for the measurement to be meaningful. Because of this nonlinearity, values of D measured at one frequency cannot easily be extrapolated to other frequencies.

Another frequency-dependent imperfection in capacitors is the effective series inductance (ESL). This is caused by the inherent inductance in leads and plates. The construction of the capacitor affects ESL; parallel and stacked plate capacitors (such as mica, ceramic, glass and some electrolytics) have much lower ESL than do wrapped foil types. Solid slug and sintered powder capacitors also have low ESL. Since even a short piece of wire is a formidable inductor at very high frequencies, microwave capacitors reduce ESL by having no leads at all.

ESL shows up in measurements taken at frequencies more than a few percent of the self resonant frequency of the capacitance and ESL. If the measurement frequency exceeds 10% of the resonance point, the capacitance will appear degraded by more than 1%. Manufacturers often supply impedance vs. frequency plots to indicate ESL. The low frequency section of the curve is dominated by capacitive reactance. The impedance bottoms out at the resonance point, at which point only ESR is significant. Above that point, inductive reactance caused by ESL dominates.

4 $D = \frac{\text{Energy in} - \text{Energy out}}{\text{Energy out}}$; therefore D represents the energy "lost" in the capacitor

TYPE	CAPACITANCE RANGE	VOLTAGE RANGE	TEMPCO ppm/°C	DF% 1 kHz	D.A. %	Leakage[1] ohm-uF
Ceramic — COG	1pF-.1uF	50-600	0±30	<.2%		5 X 10^8
COH	1pF-.01uF	50-600	0±60	<.2%		5 X 10^8
COJ	1pF-.01uF	50-600	0±120	<.2%		5 X 10^8
COK	1pF-.01uF	50-600	0±250	<.2%		5 X 10^8
U2J	1pF-.01uF	50-600	−750±120	<2%		5 X 10^8
P3K	100pF-.01uF	50-600	−1500±250	<.2%		5 X 10^8
X7R	10pF-2.7uF	50-100	+1000±3000	<2.5%		10^8−10^9
Y5F	.01-2.2uF	3-50	±2500	2-10%		10^5−10^8
Y5R	.01-2.2uF	3-50	±3000	2-10%		10^5−10^8
Y5T	.01-2.2uF	3-50	+1000±4000	2-10%		10^5−10^8
Y5V	470pF-4.7uF	50-100	±20,000	<2.5%		10^9
S2L	3-200pF	1kV-6kV	−330±500	<.6%		8 X 10^7
S3N	3-200pF	1kV-6kV	−3300±2500	<.6%		8 X 10^7
X5F	100pF-.01uF	50-600	−500±2500	<2%		5 X 10^4-10^{10}
X5U	100pF-.01uF	50-600	±7500	<2%		5 X 10^4-10^{10}
Z5F	100pF-.01uF	50-6kV	±2000	<2%		5 X 10^4-10^{10}
Z5P	.001-.01uF	50-6kV	+2500±2500	<2%		5 X 10^4-10^{10}
Z5R	.005-.1uF	50-6kV	+2500±2500	<2%		5 X 10^4-10^{10}
Z5U	.001-4.7uF	50-6kV	±10,000	<2%		5 X 10^4-10^{10}
Z5V	.001-.1uF	50-600	±10,000	<2%		5 X 10^4-10^{10}
Silver Mica	1pF-.1uF	100-2kV	±500to±10	.05-.2%[2]	1%	10^9-10^{11}
Polyester (mylar)	.001-10uF	50-1600	+400±200	.5-1%	.5%	5 X 10^8-10^{11}
Polystyrene	20pF-30uF	30-600	−120±30	.01-.1%	.02%	10^{11}-10^{12}
Polycarbonate	.001-25uF	50-400	0±100	.1-.5%	.2%	10^{10}-10^{11}
Polypropylene	100pF-.15uF	200-1600	−450±300	.01-.1%		
Parylene	.001-1uF	30-100	0±50,−200	.1-.3%	.1−1%	10^{10}-10^{12}
Teflon	.001-1uF	50-600	−200	0.1-.2%	0.2%	10^{11}-10^{12}
Paper Impregnated	.0005-100uF	200-15kV	0±500	.2-1%	2%	10^8-5 X 10^{10}
Glass	.5pF-.01uF	300-1kV	+140±25	.03-.1%		10^9
High K Glass	10pF-.01uF	50-100V	±4500	1-3%		10^9
Aluminum Foil	.5uF-1F.	3-500V	+10,000	3-50%[3]	10%	.01-10uA/uFV
Solid Tantalum	.001-1000uF	3-125	+1000	1-12%[4]	2%	.01-1uA/uFV
Tantalum Foil	.1-10,000uF	3-500V	+2500	10-20%[3]		.01-1uA/iFV

All values shown are representative figures.

[1]minimum; from manufacturers literature, package limited for small values

[2]at 1 MHz

[3]at 120 Hz

[4]at 120 Hz, 2-30% at 1 KHz.

FIGURE 7-1. CHARACTERISTICS OF VARIOUS TYPES OF CAPACITORS

Sometimes capacitors don't discharge as readily as theory predicts they should. A voltage can be noted across a capacitor even after it has been fully discharged. This effect is known as soakage, recovery voltage, or dielectric absorption (DA). DA is modelled as a secondary capacitor in series with a large resistor, parallel to the main capacitor. It is measured by charging the capacitor to a particular voltage for a specific time (greater than 1 min.), shorting it for an interval (between 1 and 10 sec.), and allowing it to recover for a specific period (greater than 1 min.). The ratio of final to initial voltages gives the value of DA.

When a capacitor is leaky, the DA appears smaller because of self-discharge effects. Similarly, dielectric absorption can be misinterpreted as leakage if leakage is measured before the effects of DA settle out. This may take less than a second or hours, depending upon the dielectric and the degree of settling desired.

There are two instances in which DA has a major effect on the capacitance indicated on the C-Meter. One occurs with large electrolytic capacitors whose shunt network models have effectively long time constants. These capacitors decrease in apparent value while being measured because the dc component in the C-Meter's waveform initially charges the shunt capacitor (Figure 7-2). After this secondary capacitor is charged, the C-Meter's charging current only measures the primary capacitance, thereby giving a lower reading.

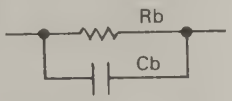
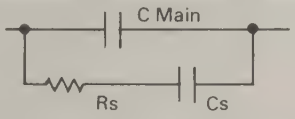
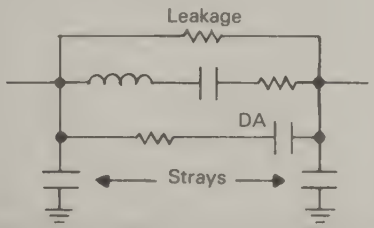
DESCRIPTION	FORMULA/SCHEMATIC
Bridges compensate for D by means of the formulas:	$Ra = \frac{D}{2\pi FCa}$ $Rb = \frac{1}{2\pi FDCb}$ $Cb = \frac{Ca}{1+D^2}$
Low D model used by bridges:	
High D model used by bridges:	
Dielectric absorption:	
ESL and ESR:	
Model of true capacitor. Capacitance and resistance are not necessarily stable with regards to voltage and temperature.	

FIGURE 7-2. MODELS OF CAPACITOR IMPERFECTIONS

The other instance in which DA has a major influence on readings occurs when the initial voltage on the capacitor exceeds the average used by the C-Meter. This can happen when the button on the C-Meter is depressed twice with the same capacitor attached. The capacitor is then being charged by the voltage absorbed in the dielectric, as well as by the test voltage. The first reading appears lower than the subsequent readings, although it is accurate in certain contexts.[5] If the test cycle time is much longer than the time constant of the dielectric (viewed as an RC shunt network), the indicated capacitance is the sum of the dielectric absorption and primary capacitance.

Small value capacitors can be tested for DA by measuring them singly and then in parallel. The different measurement times causes different amounts of soakage, and if either one or both have significant DA, the values of the two capacitors are not added accurately. Figure 7-1 indicates which dielectrics are most prone to show substantial DA.

Measurement of low capacitance values is also affected by the stray capacitance between all conductors. This also causes capacitors to show different values in circuit than on a bridge or C-Meter. Refer to Figure 7-3. Besides the capacitances between the terminals, there are stray capacitances to ground. These are most pronounced when one terminal is grounded, as in many critical timing and oscillator circuits. Bridges do not ground the capacitor under test. The C-Meter keeps one terminal as well as the front panel grounded; if the capacitor is to be used near a ground plane, it should be measured close to the front panel. Lead length should be close to that which will actually be used, as it too contributes to stray capacitance.

Manufacturers generally rate capacitors by impedance bridge methods. Large electrolytics are normally excited at low frequencies (50-120 Hz), while smaller capacitors are typically measured at 1kHz and 1MHz. Electrolytics are generally measured with a small superimposed dc bias voltage.

Capacitance measurement is meaningful only with due consideration given to the manner in which the tests were made, and with an understanding of the effects of the capacitor's imperfections. Specifying the value to a high degree of accuracy is misleading if the capacitor itself is incapable of maintaining such accuracy over a broad range of test or operating conditions.

5. It is literally correct if one relies on the definition C = Q/V, but whether it is functionally correct depends upon the context.

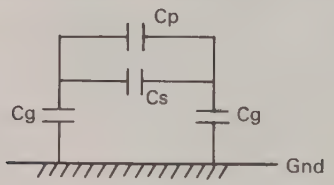
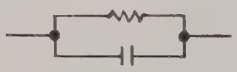


FIGURE 7-3. STRAY CAPACITANCE



Discrepancy:	.1%[3]	Series R 1%;[3]	Shunt R 0.1%;	Shunt R 1%
0-20nF	5k	30k	2000meg[1]	200m
20nf-200uf	50hm	12Ohm	2meg	200k
200uf-20mf	—	1.9Ohm	40k	4k
20mf-200mf	—	.12[2]	40k	4k

[1]Insulation resistance of virtually all capacitors in this range is greater than 10,000 megohms.
[2]ESR typically is <0.040 Ohms on capacitors of this size.
[3]Discrepancies are in the form of high readings on all ranges but the highest.

FIGURE 7-4. DEVIATION OF MEASURED VALUE FROM VALUE "C" FOR VARIOUS LOSSES

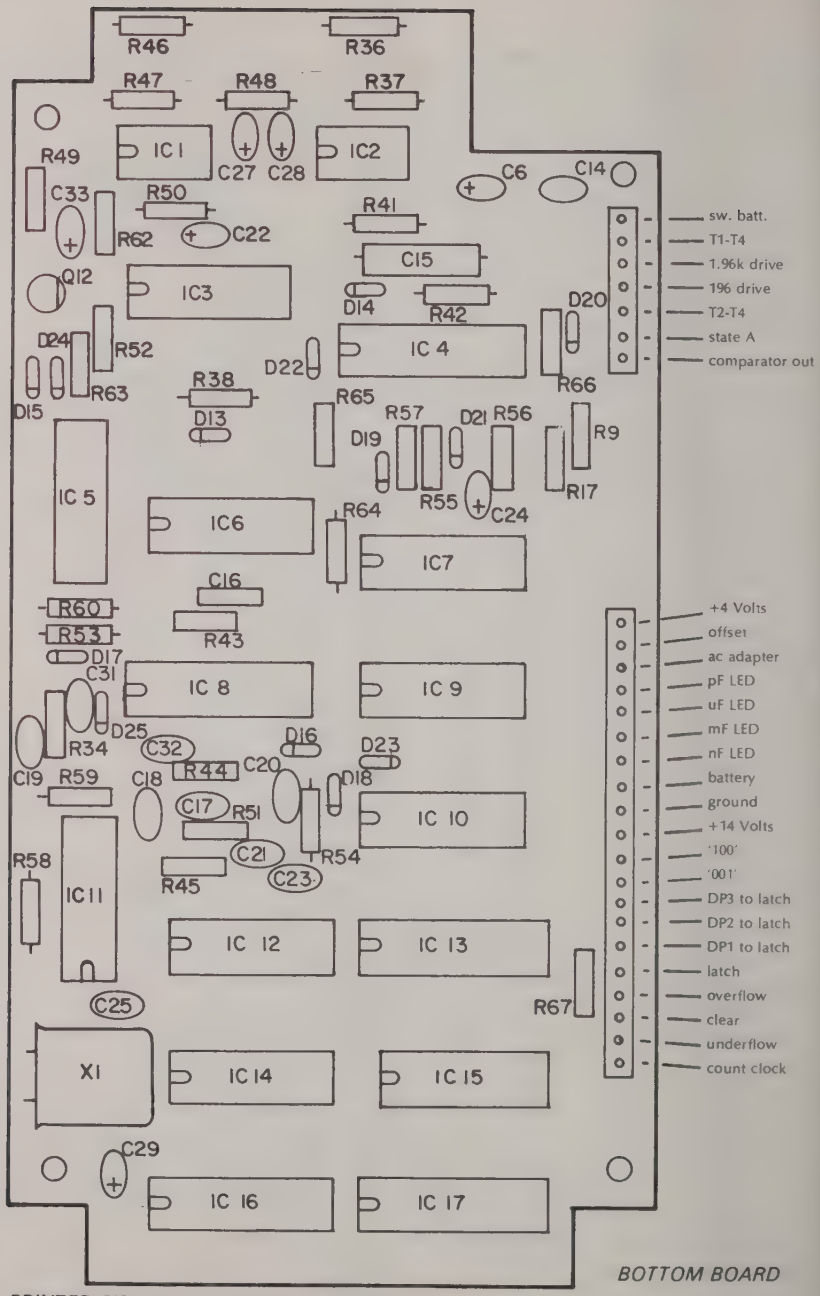
SECTION 8

PARTS LIST/ DRAWING/ SCHEMATICS

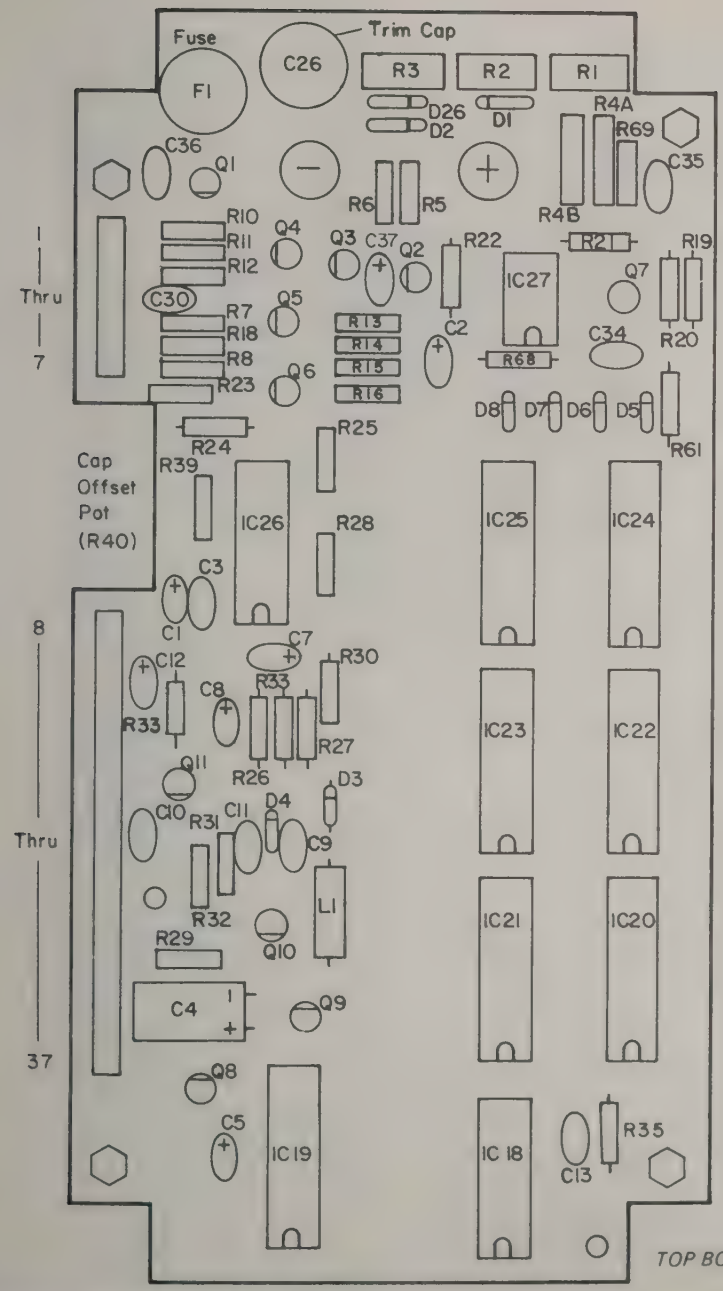
REF. DES.	PART	REF. DES.	PART	REF. DES.	PART	REF. DES.	PART
R1	100k pot	R45	51k	C21	22pF	Q3	2N2222
R2	100 pot	R46	1M	C22	1.0μF	Q4	2N2222
R3	10 pot	R47	1M	C23	120pF	Q5	2N2222
R4A	1M, 1%	R48	27k	C24	1.5μF, 15V	Q6	2N2222
R4B	960k, 1%	R49	4.7k	C25	10pF	Q7	E411
R5	1.96k, 1%	R50	1.5M	C26	10-60pF	Q8	2N2907
R6	196, 1%	R51	2.2M	C27	10μF, 15V	Q9	2N2907
R7	4.7k	R52	10k	C28	10μF, 15V	Q10	2N2222
R8	4.7k	R53	75k	C29	10μF, 15V	Q11	2N2222
R9	4.7k	R54	51k	C30	1.8nF	Q12	2N2222
R10	1k	R55	51k	C31	470pF	IC1	CA3080E
R11	10k	R56	470k	C32	220pF	IC2	CA3080E
R12	51k	R57	27k	C33	2.2μF	IC3	4030
R13	9.76k, 1%	R58	22M	C34	220pF	IC4	4449
R14	1.02k, 1%	R59	51k	C35	68pF	IC5	4011
R15	2.10k, 1%	R60	51k	C36	47pF	IC6	4001
R16	110, 1%	R61	200	C37	10μF	IC7	4075
R17	27k	R62	3k	D1	1N457A	IC8	4044
R18	10k	R63	100	D2	1N457A	IC9	4071
R19	10k, 1%	R64	51k	D3	1N4148	IC10	4075
R20	10k, 1%	R65	100k	D4	1N964B	IC11	4011
R21	4.7M	R66	390k	D5	1N4148	IC12	4071
R22	10k	R67	100k	D6	1N4148	IC13	4017
R23	11k	R68	100k	D7	1N4148	IC14	4016
R24	13k	R69	3k	D8	1N4148	IC15	4016
R25	100	C1	10μF, 15V	D9	*	IC16	4518
R26	27k	C2	10μF, 15V	D10	*	IC17	4518
R27	22k	C3	120pF	D11	*	IC18	4047
R28	150	C4	47μF, 15V	D12	*	IC19	4054
R29	4.7k	C5	2.2μF, 15V	D13	1N4148	IC20	4518
R30	22	C6	10μF, 15V	D14	1N4148	IC21	4056
R31	1k	C7	10μF, 15V	D15	1N4148	IC22	4518
R32	51k	C8	10μF, 15V	D16	1N4148	IC23	4056
R33	1k	C9	120pF	D17	1N4148	IC24	4042
R34	4.7k	C10	1nF	D18	1N4148	IC25	4556
R35	100k	C11	10nF	D19	1N4148	IC26	723
R36	1M	C12	10μF, 15V	D20	1N4148	IC27	LM311
R37	4.7k	C13	.01μF	D21	1N4148	X1	5 MHz
R38	10k*	C14	1μF	D22	1N4148	F1	112
R39	3.32k, 1%	C15	.022μF	D23	1N4148	L1	390μH
R40	1k pot	C16	27pF	D24	1N4148	LCD	336-312
R41	3.32k, 1%	C17	220pF	D25	1N4148	B1	AA cell
R42	16.9k	C17	22pF	D26	1N4742	S1	Oak 415
R43	51k	C19	120pF	Q1	2N2222		
R44	51k	C20	220pF	Q2	2N2222		

*6100-6003-1 LED

PARTS LIST



PRINTED CIRCUIT BOARD PARTS LAYOUT



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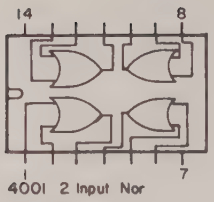
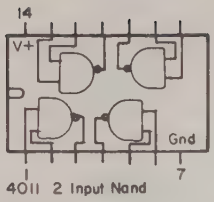


4001 2 Input Nor



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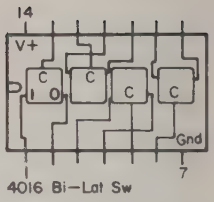
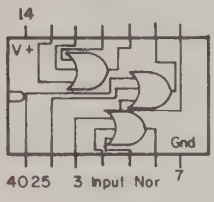
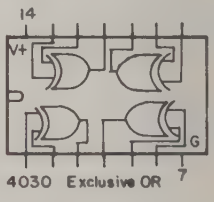


4016 Bi-Lat Sw

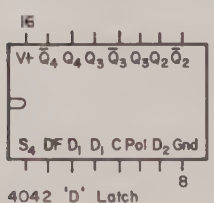
4017 Decade Counter



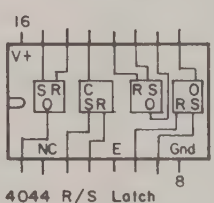
4025 3 Input Nor



4030 Exclusive OR

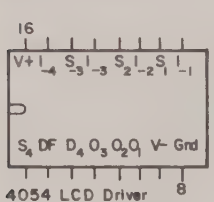


4042 'D' Latch

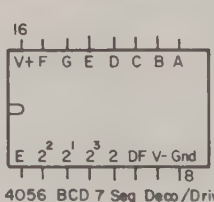


4044 R/S Latch

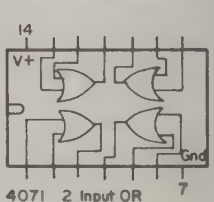
4047 Mono-Stable



4054 LCD Driver



4056 BCD 7 Seg Deco/Drive



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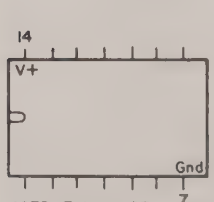
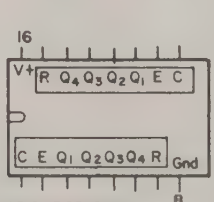
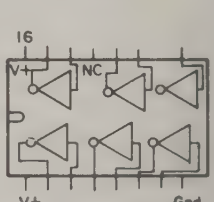


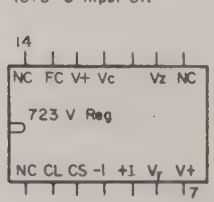
4075 3 Input OR



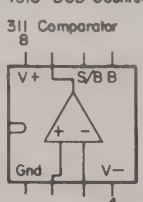
4518 BCD Counter



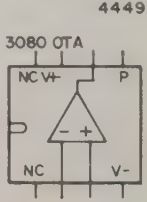
4449 Inverter



311 Comparator

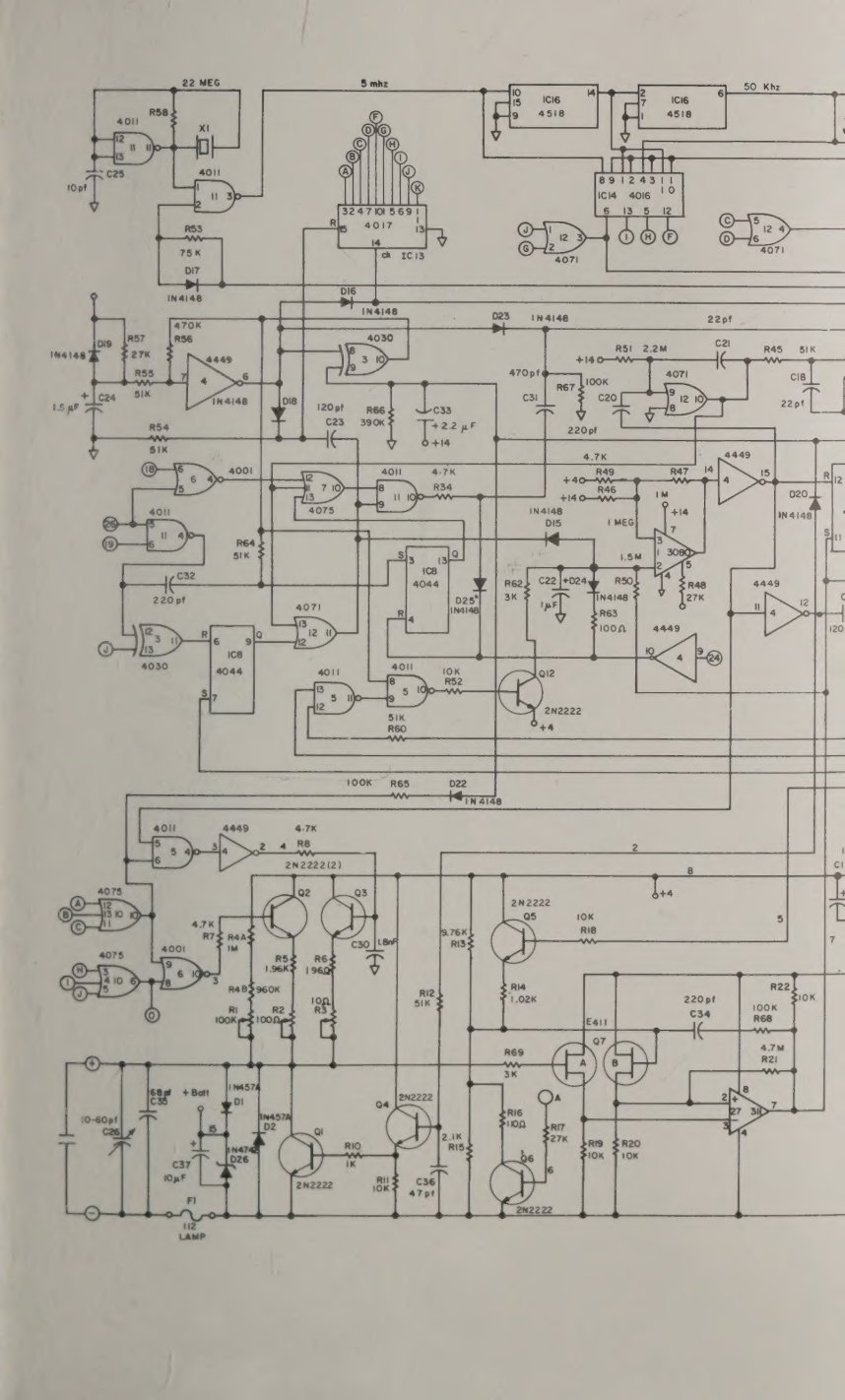


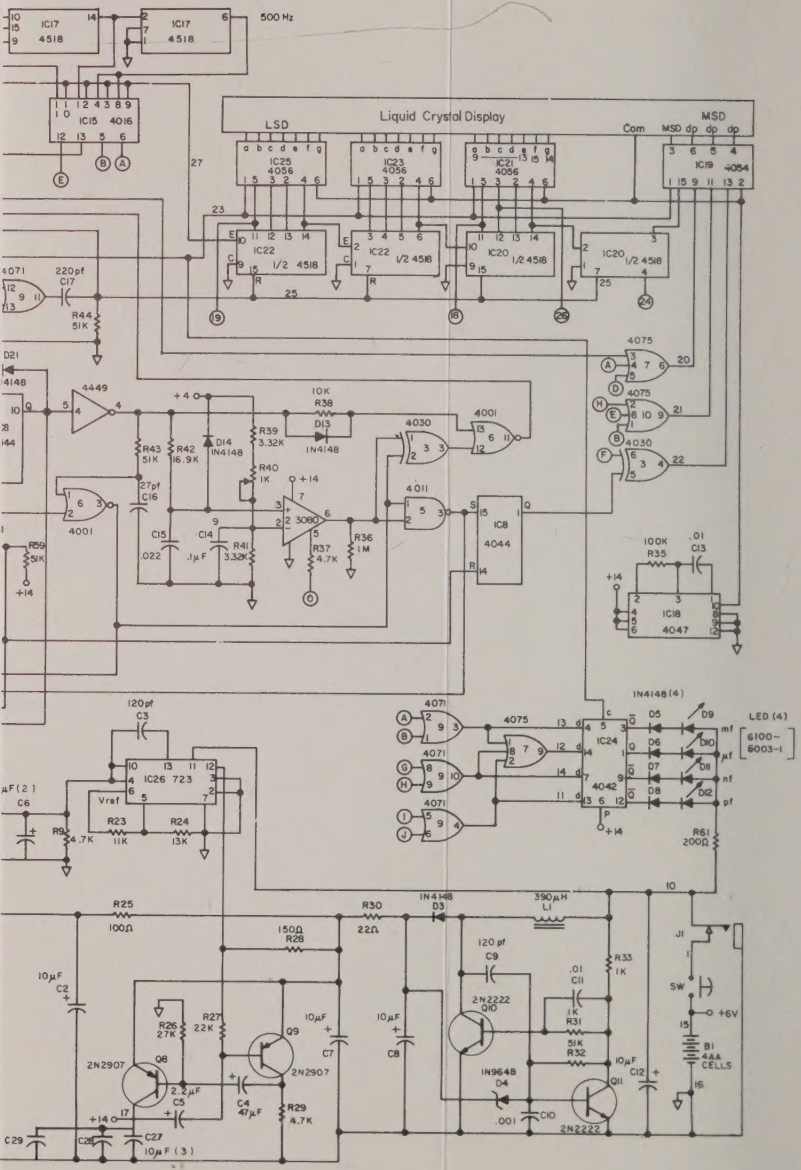
3080 OTA



Dual FET E411

INTEGRATED CIRCUIT PINOUT DIAGRAMS


22 MEG
5 mhz
50 Khz
R58
X1
C25
10pf
4011
IC16
4518
IC14
4016
IC13
4017
4071
R53
75 K
DI7
IN4148
DI6
DI9
R57
27K
R56
470K
4449
R55
51K
C24
1.5 µF
DI8
120pf
C23
R66
390K
C33
+2.2 µF
+14
R54
51K
4030
4001
4075
4.7K
R34
R64
51K
C32
220pf
IC8
4044
D25*
IN4148
R62
3K
C22
1µF
+024
R50
1.5M
R63
100Ω
R49
R46
1M
1 MEG
3080
R47
R48
27K
D15
D20
R52
10K
Q12
2N2222
R60
51K
100K
R65
D22
D23
22pf
R51
2.2M
C21
R45
51K
C18
470pf
C31
R67
100K
C20
220pf
C19
R8
2N2222(2)
Q2
Q3
Q5
Q7
Q4
Q1
Q6
R7
4.7K
R4A
1M
R5
1.96K
R6
196Ω
C30
1.8nF
R4B
960K
R1
100K
R2
100Ω
R3
100Ω
R13
9.76K
R14
1.02K
R18
10K
R12
51K
R69
3K
E411
C34
220pf
R22
10K
R68
100K
R21
4.7M
R16
10Ω
R17
27K
R19
10K
R20
10K
R10
1K
R11
10K
R15
2.1K
C36
47pf
C35
68pf
C26
10-60pf
+Batt
D1
D2
D26
C37
10µF
F1
1/2 LAMP



C-METER SCHEMATIC DIAGRAM

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